Electronic Version

Stylesheet Version v1.1.1

Description

[Ungrounded DC and AC System Fault Detection and Location System]

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of 10215310.

BACKGROUND OF INVENTION

[0002] *1. Field of the Invention*

[0003] The present invention relates to systems and methods for detecting and locating a ground fault. More particularly, the present invention relates to systems and methods for detecting and locating grounded circuits and or components on an ungrounded AC or DC system, without having to de-energize the affected circuits, and enables isolation of the energized grounded circuits from the larger distribution system.

[0004] *2. Background and Related Art*

[0005] An electric circuit provides a path for electric current to travel that is typically composed of conductors, conduct-

ing devices, and a source of electromotive force that drives the current around the circuit. Current flows in an electric circuit in accordance with several definite laws, including Ohm's law, which provides that the amount of current flowing in a circuit made up of pure resistances is directly proportional to the electromotive force impressed on the circuit and inversely proportional to the total resistance of the circuit. Ohm's law applies to circuits for both direct current ("DC") and alternating current ("AC"), but additional principles, such Thevinin's theorem, must be invoked for the analysis of complex network circuits and for AC circuits also involving inductances and capacitances.

[0006] An electric circuit may include an intentional electrical connection from a conductor to an electrical ground termed "a grounded system" or a circuit may be intentionally left ungrounded. Such ungrounded systems typically contain a ground detection device that is intentionally grounded through a resistance in the detector. This ground path only serves to provide a reference to ground from either the positive conductor or the negative conductor and should not be confused with a grounded system. In an industrial setting, ungrounded systems usually

supply many field devices such as vital loads that must remain invulnerable to spurious trips such as certain plant control functions, valve actuators, emergency equipment, etc. An electrical ground is an electrically conductive body, such as the earth, which maintains a zero potential (i.e., it is not positively nor negatively charged). An electrical connection to a ground carries current away from the circuit.

[0007] Occasionally on an intentionally ungrounded circuit, a ground fault may occur. When this happens the ungrounded circuit (unlike an intentionally grounded circuit) is designed to continue to feed the load. Grounds on ungrounded systems can be attributed to several different causes. Some of the major failures in electric equipment are caused by insulation breakdowns. The insulation is affected by aging, humidity, dust and environmental conditions, operational parameters and maintenance practices. Other types of failures include circuit board failures, moisture, bad wire joints and sleeves, leaking batteries, accidental grounds during testing, etc. or a failing component. Also, there can be multiple grounds on either the positive (hot for AC) or negative leg (common for AC) of a DC distribution system or on both legs at the same time.

A DC system may have multiple branch circuits and each branch circuit may have many components being fed by the system. Ground faults are typically categorized in one of two ways, "hard" or "soft". A hard ground is a ground fault that offers little or no resistance to current flow. A soft ground is a ground fault that offers a level of resistance above that which would be categorized as a hard ground. A ground resulting in sufficient current flow that occurs on any component will cause the ground detector device (located at the main distribution bus) to actuate.

[0008] Should a second ground occur, fault current may reach a level that could result in the de-energization of vital circuit(s). In these situations it becomes important to locate the ground fault before additional ground faults occur on the circuit. Unexpected shutdowns of electrical equipment due to faults to ground not only affect production but also may result in equipment damage, hazards to personnel and long repair times.

[0009] Ground fault detection and ground fault location do not have the same meaning. A ground detector only senses that a ground fault exists somewhere on a vast ungrounded electrical system and ground fault location is the act of finding the source of the ground fault.

[0010] Techniques currently exist that enable the detection of a ground fault on an ungrounded system. For example, ground fault detectors (ANSI device function number 64) are available that sense that a ground fault exists somewhere on a vast ungrounded electrical system. Such fixed ground-detecting equipment typically detects and indicates the presence of a ground on a large distribution system. Once the ground is detected, an alarm will sound at the larger or higher-level distribution switchgear indicating a ground fault has occurred on the system. Some contemporary ground detection devices allow multiple alarm setpoints that are initiated at various strengths of ground fault resistances. These devices will typically allow an alarm at the local switchgear when a ground fault reaches a specific magnitude. As the magnitude of the fault increases or additional faults occur on the system, a second alarm will occur, typically in the control room of the facility, indicating an urgent need to locate the fault. Thus, while techniques currently exist that will alert a user that a ground is somewhere on the system, it cannot accurately identify on which branch circuit the ground is located. In addition local alarms may go unnoticed until a second ground fault occurs, leaving vital systems at risk.

Moreover, the technique is unable to locate the actual source of the ground.

[0011] Techniques, independent of ground detectors, are also available to perform ground fault location, which is the act of finding the source of the ground. They consist of a current transformer and a method to vary the current flow in some fashion. Since, a current transformer will only provide an output when it is monitoring a rising and falling current flow, on a DC circuit, a current transformer would not normally provide an output unless the current that is being monitored is manipulated in the fashion described.

[0012] Portable ground fault locating techniques used on uninterruptible systems supplying vital loads typically attempt to locate the circuit containing the ground fault by varying the ground fault current. A current transformer is then used as a detector to sense ground fault current changes, systematically on every circuit of the system, until the circuit containing the ground fault is located. Accordingly, traditional ground fault locating equipment falls short in detecting high resistance ground faults due to the low level of ground fault current, excessive noise on the system, or a combination of both. If the ground fault current is very low, the current transformer will not provide a

measurable output which makes it impossible to locate the faulted circuit using this method. Conversely, if the noise on the system is of sufficient magnitude, the output of the current transformer may fool a technician into believing he has located the faulted circuit. Additionally, if the magnitude of the ground fault current is lower than the noise on the system, traditional fault locating equipment will not be able to distinguish between them and thus will not be able to locate the circuit containing the fault. When these situations occur, the only method that can be employed to locate the circuit containing the soft ground fault is the "breaker isolation" method. In this method the technician must systematically open each branch circuits" breaker, starting with the one offering the least risk to vital equipment and gradually moving to the ones of higher risk. This method is very undesirable and can actually put an industrial plant at more risk of inadvertent shutdown or equipment misoperation, than the actual ground fault itself.

[0013] In addition, since contemporary techniques rely on a separate distinctive detection device and a separate distinctive marginal location method, they offer very limited opportunities in locating intermittent, cycling or momentary

ground faults or multiple ground faults on an ungrounded system. An intermittent ground fault results from a ground fault occurring in electrical equipment during a specific operation but not in any specific time cycle. In an industrial setting, various types of equipment may be of a power cycling nature between on and off. If this equipment also contains a ground fault, the detector will only sense the fault when the equipment is in the "on" position but not in the "off" position. Other ground faults may be hidden in control circuit operations such as the operation of a momentary switch. The detector will sense the ground fault during the switch manipulation but not sense it when the switch is released thereby creating a momentary ground fault.

[0014] Typically, after a ground fault has been detected, an alarm is actuated, and a technician is dispatched in an attempt to locate the source of the ground fault or ground faults. During this time, the strength of the ground fault may change or the ground is or becomes intermittent, cycling or momentary consequently making the entire effort futile.

[0015] Thus, while techniques currently exist that are used in performing ground fault location, challenges still exist.

Accordingly, it would be an improvement in the art to augment or even replace current techniques for both ground fault detection and location with other techniques.

Summary of Invention

[0016] It is an overall objective of the present invention to provide an improved ground fault detection and location system, methods and apparatus for identifying and locating ground faults on normally ungrounded AC or DC systems.

[0017] A further objective of the present invention is to combine enhanced detection methods with enhanced location methods, thus forming an all-encompassing system ground fault protection system for ungrounded systems.

[0018] A further objective of the present invention is to provide an improved ground fault detection and location system, method and apparatus that eliminates the "breaker isolation technique" of locating a circuit containing a ground fault.

[0019] A further objective of the present invention is to provide an improved ground fault detection and location system, method and apparatus that locates any circuit containing a ground fault on an ungrounded AC or DC system without de-energizing the circuit.

[0020] A further objective of the present invention is to provide

an improved ground fault detection and location system, method and apparatus that enables the isolation of the grounded component of the circuit, without a loss of power to the vital load.

[0021] The present invention takes advantage of ground fault detection principles, ground fault location principles, circuit isolation principles and current transformer principles to systematically locate the source of a ground fault on an ungrounded system. An enhanced ground fault detection device (ANSI device function number 64) with several additional features and circuits to aid in location is offered that allows the present invention to be described in two facets, a permanently mounted fault detection and location system or portable ground fault detection and location system.

[0022] Implementation of the present invention enables a permanently mounted ground fault detection and location system that will detect a ground fault and locate the circuit that contains the fault, regardless of whether the fault is hard, soft, intermittent or cycling; or if the ungrounded system contains multiple ground faults. Further system troubleshooting techniques embodied can be employed to locate the component that has faulted to ground. Also the

permanent facet of the present invention combines an ANSI device 64 with ANSI 27 and 59 devices to provide under/over-voltage and ground fault protection within the same device.

[0023] Implementation of the present invention also enables a portable ground fault detection and location system to be employed that can be temporarily connected to an un-grounded circuit. The portable system will detect a ground fault when it occurs and a technician can locate the circuit that contains the fault. This operation occurs regardless of whether the fault is hard, soft, intermittent or cycling; or if the ungrounded system contains multiple ground faults. Because this facet of the invention is portable, the same techniques used to locate the circuit that contains the ground fault can be used to locate the component that has faulted to ground.

[0024] Furthermore, implementation of the present invention recognizes that grounds on ungrounded systems normally occur on lower amperage circuits and that these circuits are generally not located in the main switchgear. They are normally located in smaller distribution switchgear that is fed from the larger main switchgear. The portable facet of the present invention contains an option that will allow an

independent power supply to be connected to the present invention to provide a separate ungrounded power source to a circuit suspected of being faulted, through the present invention's ground detection circuitry. The separate power source is paralleled onto the grounded circuit and the grounded circuit's normal source is removed, thereby keeping the load energized at all times but isolated from the ungrounded system. Should a ground fault occur on the isolated system the portable detection device will sense it and further troubleshooting to determine the source can occur without impact to the normal ungrounded system.

[0025] Accordingly, the systems and methods of the present invention locate any grounded circuit on an ungrounded AC or DC system without de-energizing the circuit. Once the grounded circuit is located, further troubleshooting can be performed to isolate the grounded component. These and other features and advantages of the present invention will be set forth or will become more fully apparent in the description that follows and in the appended claims. The features and advantages may be realized and obtained by means of the instruments and combinations particularly pointed out in the appended claims. Further-

more, the features and advantages of the invention may be learned by the practice of the invention or will be obvious from the description, as set forth hereinafter.

Brief Description of Drawings

[0026] In order that the manner in which the above recited and other features and advantages of the present invention are obtained, a more particular description of the invention will be rendered by reference to specific embodiments thereof, which are illustrated in the appended drawings. Understanding that the drawings depict only typical embodiments of the present invention and are not, therefore, to be considered as limiting the scope of the invention, the present invention will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

[0027] Figure 1 illustrates a "larger switchgear fed from a charger and a battery bank. The "larger switchgear" is depicted feeding smaller distribution switchgear with a normal service ground detector monitoring the entire system for ground faults. A separate illustration depicts a typical branch circuit.

[0028] Figure 2 illustrates a representative ground detection device, field circuit and field device with no ground fault

present.

[0029] Figure 3 illustrates a representative ground detection device, field circuit and field device with a ground fault present.

[0030] Figure 4 illustrates a contemporary method of ground location.

[0031] Figure 5 illustrates the location of a meter connected between the center point of the balance resistors and ground that will measure offset voltage and ground current.

[0032] Figure 6 illustrates a ground fault current "oscillator circuit" being connected between the center point of the ground detector and ground.

[0033] Figure 7 illustrates the wireless hand held locating signal tracer of the present invention.

[0034] Figure 8 illustrates the CMV (Common Mode Voltage) connection.

[0035] Figure 9 illustrates a representative "module" of the permanent facet of the present invention connected to a typical circuit and field device.

[0036] Figure 10 illustrates one representative mechanism for attaching the portable facet of the present invention onto a suspect circuit containing a ground fault.

[0037] Figure 11 illustrates one representative technique for feeding a suspected circuit from an isolation device through the present invention onto a suspect circuit containing a fault to ground.

[0038] Figure 12 illustrates one representative portable facet of the present invention with an internally mounted current transformer being connected to a suspected circuit containing a fault to ground.

DETAILED DESCRIPTION

[0039] The present invention relates to systems and methods for locating a ground fault. More particularly, the present invention relates to systems and methods for locating any circuit containing a ground fault on an ungrounded AC or DC system, without de-energizing the circuit, and enabling isolation of the grounded component of the circuit.

[0040] Figure 1 illustrates a typical DC ungrounded vital system. The illustration includes a charger to feed the vital larger switchgear with power and maintain the battery bank with charging power. Should the charger become inoperable, the battery bank will maintain the larger switchgear with power until its charge is depleted. A ground detector device is located at the larger switchgear to detect the presence of a ground fault on any part of the system and to

alert plant operators either locally or remotely that a ground fault has occurred somewhere on the system.

[0041] Some embodiments of the present invention enable a ground detector device 64 to combine circuitry that will also aid in the location of a ground fault. The ground detector is considered an ANSI (American National Standards Institute) device function number 64. Figure 2 illustrates a typical ground detector device, connection A is for illustration purposes only to depict a field device's electrical relationship to the ground detector without depicting all the branch circuitry involved. As shown in Figure 2 for a "120" volt system, the ground detector typically is comprised of a voltage divider circuit consisting of two balance resistors of equal values. One of the balance resistors is connected from positive (hot for AC) to an intentional ground and the other from negative (common for AC) to the intentional ground. When a ground fault is not present, there is no ground current flow and the voltages across each resistor to ground are the same or "balanced". As shown in Figure 3, (voltage values are for illustration purposes only) when a ground fault occurs in a field device or cabling, the voltages across the resistors become "unbalanced". This due to the ground fault current flowing

from the faulted field device through the un-intentional ground to the intentional ground at the ground detector. The voltages across the balance resistors change according to the amount of ground current flowing. This method can detect a ground fault but cannot distinguish which branch circuit contains the ground fault.

[0042] Figure 4 depicts the contemporary method of ground location. The ground detection device is removed and replaced with the locating equipment. The ground current "Ig"is varied in some fashion and the clip-on current transformer (CT) is moved about the branch circuits. When the branch circuit that contains the varied ground current is located, the CT will output a current proportional to the ground current and light the LED of the ground locating equipment (shown in red). Because the ground fault current is proportional to the ground fault resistance, the higher the resistance the lower the ground fault current. This method offers only marginal success when attempting to locate high resistance ground faults or if noise on the branch circuit is greater than the ground current.

[0043] In the following six paragraphs, each of the main circuits or components that make the present invention a unique ground fault detection (ANSI device function number 64)

and location system will be discussed in detail. The following paragraphs illustrate components and circuitry that the present invention incorporates in its permanent and portable ground fault detection and location configurations, thereby making the present invention unique in design. These circuits or components are "Offset voltage", "continuous offset voltage", "ground fault current measurements", "ground fault current oscillation", "common mode voltage" and a "cordless hand held signal tracer".

[0044] Some embodiments of the present invention enable the ground fault detector to contain circuitry that will allow the measurement of "offset voltage" to be taken. As shown in Figure 5, the "meter" is a voltmeter and is depicted as a hand held meter only for illustration purposes, as the voltmeter is to be built into the ground detection device. An offset voltage measurement is obtained from the meter by removing the intentional ground from the ground detector and measuring the voltage or difference of potential between the center point of the balance resistors to ground. 62882471On an ungrounded system that has a fault to ground, this measurement will allow a technician to determine the percentage of the field device where the ground fault has occurred. 62882471MSOffice

62882471Needs more explanation and possibly a drawing reference. The polarity of the voltmeter will also indicate whether a ground fault has occurred nearer the positive side from the center of the field device for DC circuits (hot side for AC circuits) or the negative side (common side for AC circuits). After the measurement has been taken, the intentional ground will be restored to the center point of the balance resistors.

[0045] Some embodiments of the present invention enable the ground fault detector to contain circuitry that will allow a continuous offset voltage reading (as described above) to be taken by connecting a chart recorder to "test lead connecting jacks" on the ground fault detector. A continuous ground fault can be monitored in this fashion to determine if its ground fault strength 62882677or percentage of the field device that the ground fault has occurred at62882677MSOffice 62882677Could be confusing if not clearly explained. See previous comment., has changed over time.

[0046] Some embodiments of the present invention enable the ground fault detector to contain circuitry that will allow the measurement of "ground fault current" to be taken, as shown Figure 5, where the "meter" is now an ammeter.

Ground fault current is the flow of current from the field device fault to ground (unintentional ground) to the ground detector intentional ground. This measurement will also be used to determine the strength of the ground fault.

[0047] Some embodiments of the present invention enable the ground fault detector to initiate ground fault current oscillation. Ground fault current oscillation is used as a ground fault location technique. It is accomplished by changing the steady state DC ground fault current to an oscillating current for DC systems or by changing the rate of oscillation of AC ground fault current to a slower rate, as shown in Figure 6. The oscillation circuitry is built into the ground detector, so that when a ground fault occurs, and location techniques are to be employed, the ground fault current can then be oscillated at a rate of less than 60 Hertz.

[0048] Some embodiments of the present invention enable detecting the ground fault current oscillations, produced by the ground detector device, with a hand held signal tracer. The tracer is comprised of a current transformer, a signal detector and an indication light (LED), see Figure 7. The signal detector is comprised of common circuitry that is

designed to accept or pass the frequency that the ground fault current is being oscillated at and reject or block all other frequencies. Using this technique, the hand held signal tracer will not inadvertently actuate by detecting random noise frequencies and random frequencies will not interfere with the ground fault location method. The detector can also be comprised of Phase Lock Loop (PLL) circuitry (common to the industry) that will enable it to be wireless and independent of the ground fault detector. The technician can therefore initiate ground fault current oscillation and freely move about the suspected circuit and components and attempt to locate the oscillating ground fault current signal. Multiple hand held signal tracers can also be used or positioned at various points along the suspect circuit to assist and expedite fault location.

[0049] Some embodiments of the present invention also recognize in situations where the ground fault current is very low due to a very high resistance fault to ground, the ground oscillation current may be too small to detect with the hand held signal tracer. Therefore a common mode voltage (CMV) is utilized to raise the voltage across the actual ground resistance and thereby increase the fault

current. A "Common Mode Voltage" is a voltage introduced by removing the intentional ground from the ground detector and adding a voltage source or power supply between the center point of the ground detector and the intentional grounding point of the ground detector, as shown in Figure 8. This technique will raise the ground fault current to a level where the hand held signal tracer can detect it.

[0050] Accordingly, as will be further discussed below in the following four paragraphs, those skilled in the art will appreciate that the following embodiments of the present invention listed for representative illustration only, allow it to be used as a permanently mounted ground fault detection and location system.

[0051] Some embodiments of the present invention's ground detector allow it to be an enhanced replacement of the "normal service" ground detector at the larger switchgear, as shown in Figure 1, and become a permanently mounted protective device. The permanently mounted ground detector includes contacts to operate a local or remote alarm or both. If a hard ground is detected and is continuous, the "hard ground" contacts of the detector would remain closed until the ground is eliminated and the local or re-

mote alarm would not be able to be reset until the "hard ground" has been cleared. If a soft ground comes in and stays in, only a momentary signal would be sent to the local or remote alarm that could be reset even if the "soft" ground is continuous (still in). After a specified (adjustable) amount of time, and if the soft ground is still in, then the device sends another signal to the remote alarm, verifying that a soft ground still exists. If the soft ground becomes a hard ground, then the alarm contacts would remain closed to the remote alarm.

[0052] Some embodiments of the present invention's ground detector allow it to monitor voltage conditions and actuate a set of contacts for an adjustable under-voltage condition or an over-voltage condition; thereby, with the present invention the 64 device, the 27 device and the 59 device are built into one device. These contacts can be used to initiate a local or remote alarm, trip or both.

[0053] Some embodiments of the present invention allow an industrial plant to utilize as many clip-on current transformer detectors as desired, monitoring every branch circuit as necessary.

[0054] Some embodiments of the present invention enable detecting the ground fault current oscillations, produced by

the permanently mounted ground detector device, by the use of permanently mounted current transformer modules at each breaker, see Figure 9. These modules serve to amplify the ground fault current oscillations produced by the ground detector device and illuminate the LED indication, indicating a ground fault exists in the circuit that the module is monitoring. Amplification of the ground fault current oscillation is achieved by "wrapping" the circuit primary leads around a current transformer, the amount of amplification is proportional to the number of "wraps", 10 wraps will produce a "10 times" amplification. A "module" contains a current transformer, pre-wrapped primary leads, a signal detection circuit and an indicating LED. The advantage of the previously discussed two paragraphs is that circuit ground fault location occurs without any human intervention. Moreover, the location is performed continuously, 24 hours a day, seven days a week. Furthermore, the present invention will be able to capture momentary, cycling, intermittent or multiple ground faults.

[0055] Accordingly, as will be further discussed below in the following three paragraphs, those skilled in the art will appreciate that the following embodiments of the present invention listed for representative illustration only, allow it

to be used as portable ground fault detection and location system.

[0056] Some embodiments of the present invention's ground detector allow it to be a portable ground detection and location system. Figure 10 illustrates the present invention housed in a portable case. The normal ground detector device is removed temporarily from the larger switchgear during troubleshooting. The portable ground detector/locator is connected to circuits suspected of having a ground fault and the ground current, if present, is oscillated while the hand held signal detector is clipped around the cable feeding the field device. If the field device or cabling contains the ground fault and the ground current is of sufficient magnitude, the LED on the hand held detector will illuminate.

[0057] Some embodiments of the present invention enable the field device to be fed through the portable ground detector/locator by an isolation device, see Figure 11. The nature of the "isolation device" is to change the electrical energy supplying its input to another form of energy, transfer this form of energy to the output and to change the energy back to electrical energy. However, the input and output remain electrically isolated by no physical

electrical connection from input to output, hence the term "isolation device". The output can then be paralleled onto an existing normally energized source at a junction point and the normal source removed. The load will now be electrically isolated from the normal distribution system without ever being de-energized. Thus, any ground that comes in on the secondary or load side of the isolation device is isolated from the system feeding it. Each circuit can then be isolated one at a time, without de-energizing them, until the circuit that contains the ground fault is found. Such an isolation device comes in several forms, such as an AC-to-AC transformer or DC-to-AC converter for AC systems or a DC-to-DC converter or AC-to-DC converter is used for DC systems or other such converters that can produce an output voltage matches the normal ungrounded system voltage. In addition the ground fault detector/locator may remain as a separate device or may be built into an isolation device.

[0058] Some embodiments of the present invention enable detecting the ground fault current oscillations, produced by the ground detector device, by the use of a permanently mounted current transformer in the ground detector itself. In effect the module of Figure 9 is built into the portable

unit, rather than installing modules at each circuit. Figure 12 illustrates a detector/locator device with an internally mounted current transformer. If a ground fault occurs that is not of sufficient magnitude to detect with a hand held detector, the ground fault detector/locator can be fed from junction point A of the circuit. Then the output of the detector/locator is connected to junction point B. The tie between junction point A and junction point B would then be broken so that the field device is now fed through the ground fault detector/locator. If a high resistance ground is on the suspected circuit, the ground fault current will be amplified according to the number of "wraps" on the internal mounted current transformer.

[0059] Thus, as discussed herein, the embodiments of the present invention embrace systems and methods for locating a ground fault. More particularly, the present invention relates to systems and methods for locating any faults to ground on an ungrounded AC or DC system without de-energizing the circuit, and enabling isolation of the grounded component of the circuit. The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all re-

spects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope.